Self-reliance in water treatment: Providing safe drinking water to communities using charcoal filtration to remove pesticides

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ABSTRACT

Pesticide contamination of drinking water is a significant problem in developing countries where due to inadequate regulations over 70% of agrichemicals used intensively are banned or heavily restricted in the West. Pun Pun organic farming community in northern Thailand is committed to practicing a variety of sustainable and self-reliant living techniques. A reservoir nearby is contaminated by agricultural (including pesticide) runoff from surrounding farms. We are developing a simple, robust and inexpensive technology to purify water thus providing the Pun Pun community with a stable, year-round source of safe drinking water using locally sourced labor and materials.

INTRODUCTION

The environmental and human health consequences of widespread application of large quantities of hazardous agrichemicals are a mounting concern around the globe. In the United States, for example, a recent study by the Center for Disease Control detected pesticides and their breakdown products in 100% of test subjects. The highest concentrations of many agrichemicals were detected in women of childbearing age, children and Mexican Americans (1).

The situation in the developing world is even worse, where agrichemical corporations find markets for many of their products deemed too hazardous to human health and the environment for sale in Western countries. For example, each year the US produces hundreds of millions of pounds of pesticides considered too dangerous for domestic use. Meanwhile, over 70 percent of the pesticides used in Thailand and India are banned or severely restricted in the West (2). A survey by the Thai National Environment Board found residues in 86 percent of water samples (3). Furthermore, in the Indian state of Punjab DDT and BHC – agrichemicals banned in the west – have been widely detected human breast milk (4).

A survey of the agrichemical products in common usage around the Pun Pun community in northern Thailand revealed that, out of 34 substances, 19 exhibit moderate to highly acute toxicity to humans, 8 are possible human carcinogens and 5 are known human carcinogens, 9 are cholinesterase inhibitors (indicating neurotoxicity), 10 are suspected endocrine disruptors, 6 are reproductive or developmental toxins, 21 are classified as “Bad Actors” by the Pesticide Action Network[*], and 13 represent significant threats to groundwater contamination.

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[*] According to the Pesticide Action Network, “Bad Actors” are chemicals that exhibit one or more of the following properties: high acute toxicity in humans, cholinesterase inhibition (indicating neurotoxicity), known or probable carcinogenicity, known reproductive or developmental toxicity, or are known to constitute a groundwater pollution threat.

Contamination of drinking water supplies by agricultural runoff is one of the principal routes of exposure to chemical pesticides. This paper describes a DIY (Do-It-Yourself) drinking water purification system using simple, inexpensive and readily available materials designed to effectively remove pesticides and other chemical contaminants. This system thereby enhances the potential for local self-reliance in the vital sector of drinking water.

Carbon filtration

The US EPA, the World Health Organization and several academic studies identify granular activated carbon (GAC) as the best available technology for the control of many agrichemicals and synthetic organic chemicals in drinking water (5,6,7,8). GAC is made from charcoal, by "activating" it using a variety of physical or chemical processes designed to greatly increase the microscopic surface area of the material. A few grams of industrial grade GAC, for instance, can have a surface area equal to a football field. This highly reactive surface area attracts dissolved contaminants and binds them electrochemically.

Carbon filters are effective for removing chlorine, mercury, iodine, and some inorganic compounds as well as many problematic organic contaminants such as hydrogen sulphide, formaldehyde and volatile organic compounds (VOCs). Activated carbon does not bind well to certain chemicals including lithium, alcohols, glycols, ammonia, strong acids and bases, metals, and most inorganic substances such as sodium, lead, iron, arsenic, nitrates and fluoride.
As a general rule, carbon will bind non-polar materials while polar materials will tend to remain in aqueous solution. Most pesticides are organic and strongly non-polar and thus should display an affinity for adsorption onto the carbon surface.

Water contaminants that can be reduced to acceptable standards – according to EPA National Drinking Water Standards – by activated carbon filtration include: organic arsenic, chromium and mercury complexes as well as inorganic mercury, benzene, endrin, lindane, methoxychlor, 1,2-dichloroethane, 1,1-dichloroethylene, 1,1,1-trichloroethane, trihalomethanes, toxaphene, 2,4-D, 2,4,5-TP (Silvex) and p-dichlorobenzene.

Carbon filters have limited capacity for removing microbial contaminants and should not be considered a sufficient method for eliminating this risk. The World Health Organization recommends coupling charcoal treatment with chemical (e.g. iodine, chlorine) or UV disinfection to ensure neutralization of microbial pathogens.

UV radiation is the surest method for biological decontamination, though until recently it has been too delicate, expensive, complicated a resource intensive for use at the household or community scale in developing societies. Recently however, researchers and engineers have pioneered the development of simple, inexpensive and robust UV systems. The non-profit US- and Vietnam-based MEDRIX Corporation has extensive experience deploying such a system in communities throughout Southeast Asia. We have partnered with MEDRIX to receive materials and training to install a number of UV units at the field site in Thailand.

However, biological contamination of drinking water is only part of the problem, especially when considering pesticides and other agricultural runoff. Filtration with ceramics, chemical treatment and UV radiation will not remove pesticides from drinking water. Strategies for chemical decontamination are often scientifically complex, dependent upon advanced and sophisticated technologies and materials, and require large-scale operations to be economical. They are thus expensive and resource- and capital- intensive, and therefore out-of-reach for most communities in the developing world.

Unfortunately pesticide contamination of drinking water is a worsening worldwide problem, in developed as well as developing countries. In the US, a recent CDC study showed 100% of test subjects to be carrying traces of pesticides in their bodies, with the average person carrying at least 13 different agrichemicals (1). These data are for average adults – children and pregnant women were found to contain higher concentrations. Furthermore, chemical pesticides in general and many of the pesticides found in the test subjects in particular have been linked to serious short- and long-term health effects including infertility, birth defects and childhood and adult cancers.

The situation is much worse in Thailand where there are essentially no regulations on the types and amounts of agrichemical products that are applied. Over 70% of the pesticides used in Thailand are banned or heavily restricted in the West due to their toxic effects on ecosystems and human health (2).

Purpose

The purpose of this project is to develop an inexpensive system for effectively removing pesticides and other chemical contaminants from drinking water. The system must be simple, efficient and robust, and constructed using locally sourced labor and materials. Charcoal (graphite carbon) is a dirt-cheap material that has been manufactured worldwide for millennia, and because of its electrochemical surface properties has great potential for effectively removing agrichemical contaminants from water.

Charcoal itself is made by pyrolizing – heating in the absence of oxygen – wood or other organic matter such as coconut or rice husks, nut hulls, peat, etc. While it isn't possible to produce high-grade activated charcoal without an industrial process, charcoal with a lower, but still significant, reactive surface area can be readily produced in earthen kilns. Researchers have observed, for instance, a low-grade char produced by burning wheat straw to be about one-third as efficient as industrial activated carbon for adsorbing particular dissolved pesticides (9, 10, 11).

This finding suggests that effective home water purification systems can be constructed inexpensively using homemade charcoal. Of course, carbon-based water filters are commercially available in most countries although they are expensive, and prohibitively so for most people in the developing world. Besides, charcoal has many uses in addition to water filtration. For example, it is the preferred cooking fuel for the majority of rural people in the developing world who cook indoors over an open fire as it burns longer and hotter than the common alternatives (cornhusks, bamboo) and produces less smoke.

Charcoal also can be pulverized and used as an additive to bar soap as a scrubbing aid and skin exfoliant. Very finely ground charcoal has medicinal qualities and is used to treat stomach and enteric infections, as well as poisonings and overdoses following oral ingestion (it prevents absorption of the poison by the gastrointestinal tract).

Wood vinegar (pyroligneous acid) is a by-product of the charcoal making process. It is distilled by passing the smoke through a long chimney or heat exchanger to encourage condensation of water vapor containing a mixture of volatile organic compounds driven off from the pyrolizing wood. It is reputed to be a natural aid with various uses including mild pain relief such as tooth aches, and to sterilize and promote the healing of minor wounds. Wood vinegar is also a mild natural pest deterrent and can be applied to crops, or to wood surfaces to protect from termites.

Making charcoal using an adobe kiln

The prototype of the system described here has been developed for a self-reliant community in northern Thailand. The Pun Pun Organic Farm and Seed Center, the Panya Sustainable Living Project and the You Sabai Thai Cooking School form a community of about 30 people located 50 km north of Chiang Mai city. This community's mission is to provide a working example of locally self-reliant, sustainable living through permaculture, organic farming, seed saving and natural building.

A year-round source of freshwater is available to the community from a network of irrigation canals fed by a nearby reservoir. However, prior to consumption this water must be treated for possible contamination by fertilizer and pesticide runoff from neighboring agricultural zones afflicted by conventional (i.e. agrichemical intensive) farming practices.

For this, we have constructed an adobe kiln in which to make charcoal. Adobe bricks are made by mixing mud, roughly 80 percent sand and 20 percent clay, with fibrous organic material such as chopped straw or rice husks. (In Thailand we use rice husks as they are superabundant.) This adobe mixture is poured into wooden molds and the bricks allowed to harden in the sun over about a week's time. This kiln design requires about 80 bricks.

The bricks were stacked in an approximate beehive shape about 1 meter in inner diameter and mortared together with a similar mixture of mud and straw or rice husks. The heat intake is approximately cylindrical, about 24 long and 8 inches in diameter. Cob – a mixture of mud and straw – was applied to build up and shape the outer surface of the kiln and to provide additional insulation. The entire kiln was plastered with a sand-rich mix of mud, omitting organic material that would burn during use in the interior plaster.

The lid is about eight inches thick and made of cob reinforced with wood, steel rebar, and medium-gauge wire mesh. Cob was first applied beneath the frame. With the frame in place, cob was applied to the frame interior. Then the upper layer of wire mesh was nailed into place and cob applied over the top. We made efforts to commingle the layers of cob with each other as much as possible. Nails sticking out of the wood frame provided additional surfaces for cob attachment. A layer of sand-rich earth plaster completes the lid. Holes were drilled in the four handles protruding from the cob for connection to a rope and pulley system. Owing to its weight,

we installed a block-and-tackle mechanism attached to the center support beam of the kiln building for raising and lowering the lid.
The chimney, made of tin metal and jacketed by a flowing water heat exchanger, connects to its earthen base that opens at the bottom-rear of the kiln interior. Smoke from the charcoal making process condenses in the chimney and is collected as wood vinegar, a useful natural pest deterrent. Effluent water heated by the smoke will be used to supply a hot shower or stored for watering the nearby gardens. (A simpler chimney can be constructed using a long piece of thick bamboo; however in this instance we wanted to experiment with the condenser to gauge the degree of enhancement of wood vinegar collection, as well as make use of the source of hot water.)

We estimate that the kiln will provide perhaps as much as 50 kilograms (110 lbs) of charcoal per batch. Once a sufficient quantity (mass) of charcoal is obtained, it is be pulverized into grains fine enough to pass through a 3 millimeter sieve. The grinding process is necessary to increase the material's surface area and enhance contaminant adsorption. The plastic mesh bags that produce (e.g. potatoes) is sold in are widely available, are free or inexpensive, and make a good sieve for the pulverized carbon.

Treatment system design

How much charcoal is necessary to treat a given volume of drinking water depends on the concentration of contaminants in the water as well as the adsorption capacity of the pulverized charcoal. Here we have made conservative estimates based on the scientific literature regarding these terms in order to design a system that we can be reasonably confident will produce clean water. Accordingly, we find the ratio 5 grams of charcoal to 1 liter of water to be sufficient for our design.

With this ratio, and assuming the EPA recommended daily water intake of 2.5 liters per person per day, roughly 4.5 kilograms (about 10 lbs.) of charcoal are required to supply drinking water to one person for one year. For our system in Thailand, given the hot tropical climate and the demanding nature of the farm work performed by community members, we doubled the drinking water intake to 5 liters per person per day. This results in our system design requiring 9 kilograms (20 lbs.) of charcoal per person to meet one year's drinking water needs.

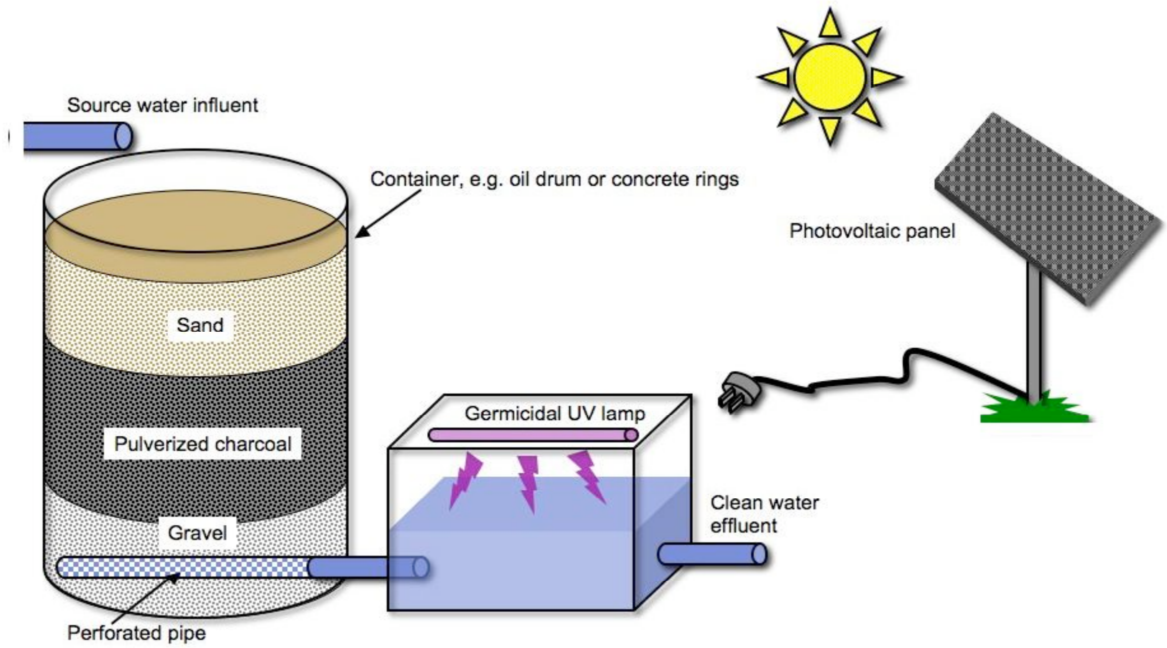
Furthermore, laboratory analysis of our charcoal filter medium as well as of local water supplies may permit the amount of charcoal required per liter to be reduced significantly. We have established contact with university laboratories in the US to perform these analyses – the results, insofar as they affect the treatment system design or lifetime, will be reported in subsequent publications.

Here we use a three-stage treatment system: a sand pre-filter followed by a pulverized charcoal filter and germicidal UV lamp.

Conservative estimates suggest that the sand layer should be about 50 centimeters thick. A diffuser plate is placed over the sand to reduce the turbulence of the influent and prevent channels forming through the sand. The thickness of the charcoal layer will depend upon how many people are using the system as well as its desired lifetime (i.e. the time until the charcoal

has to be replaced). The purpose of the gravel layer is to prevent clogging of the perforated pipe by carbon granules – this layer need only be about 20 centimeters in thickness.
Finally, we recommend running the filtered water under a germicidal UV light to eliminate bacterial and viral contaminants. Application of germicidal UV systems is widely described in other publications. A combined system of charcoal filtration and UV decontamination represents, in our estimation, the best available technology to ensure a plentiful supply of clean drinking water.

Proposed treatment system design:



In conclusion, employing this system provides a demonstration of a working prototype for a simple, effective and inexpensive drinking water system extensible to communities worldwide seeking to advance their practice of self-reliant living.

Benefits

The abundant use of pesticides in Thailand that are banned in the West highlights the need for education, empowerment of local farmers and farm workers and our motivation for designing an effective drinking water treatment system that is simple and elegant in design, inexpensive to build, operate, and maintain that will enhance the potential for community self-reliance in the vital sector of drinking water.

This project will provide a steady supply of safe drinking water to a community of about 50 people in perpetuity. Furthermore, this project represents a proof-of-concept for a simple, low-cost technology that will enable people worldwide to insure the safety of their drinking water in a self-reliant manner.

Since the proposed water treatment system functions as a demonstration for visitors to the community, it presents a teaching opportunity to discuss not only the principles of water treatment but also the economic and ecological context in which the project arises: namely, the widespread and intensive application of chemical pesticides as an integral aspect of industrial agriculture methods. These discussions will foster debate and action to address the manifold deleterious practices of industrial agriculture that have caused a great deal of imbalance between human systems and the natural environment.

REFERENCES

1. Chemical Trespass Pesticides in Our Bodies and Corporate Accountability. Kristin S. Schafer, Margaret Reeves, Skip Spitzer, Susan E. Kegley, Pesticide Action Network North America. May 2004 (http://www.panna.org/panna/)
2. Pesticide Use in Thailand. Pesticide Action Network North America Updates Service (PANUPS). Pesticides News, March 1997. Accessed on line 03/21/07. (http://www.panna.org/panna/)
3. Analysis of Crop Protection Policy in Thailand. Jungbluth F. Thailand Development Research Institute. TDRI Quarterly Review Vol. 12 No. 1 March 1997, pp. 16-23. (http://www.tdri.or.th/library/quarterly/text/m97_3.htm)
4. The state of India's environment 1984 - 1985. Argawal A et al. Centre for Science and Environment, New Delhi, 1985.
5. US EPA. National primary drinking water regulations; final rule. Federal Register, 30 January 1991. 1991; 56 20: 3526 3597.
6. World Health Organization website: (http://www.who.int/water_sanitation_health/dwq/wsh0207/en/index6.html) section 2.3 Charcoal and activated carbon adsorption
7. Pontius F. An update of the federal drinking water regs. J AWWA 1995; 87: 48-58.
8. Pesticide Adsorption by Granular Activated Carbon Adsorbers. 1. Effect of Natural Organic Matter Preloading on Removal Rates and Model Simplification. Matsui Y, Knappe DRU, Takagi R. Environ. Sci. Technol. 2002, 36, 3426-3431.
9. pH-Dependence of Pesticide Adsorption by Wheat-Residue-Derived Black Carbon. Yang Y, Chun Y, Sheng G, and Huang M. Langmuir 2004, 20, 6736-6741.
10. Pesticide Adsorptivity of Aged Particulate Matter Arising from Crop Residue Burns. Yang Y, Sheng G. J. Agric. Food Chem. 2003, 51, 5047- - 5051.
11. Enhanced pesticide sorption by soils containing particulate matter from crop residue burns. Yang Y, Sheng G. J. Environ. Sci. Technol. 2003, 37, 3635-3639